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Design of spatial PGIS-MCDA-based land assessment planning for identifying sustainable land-use adaptation priorities for climate change impacts

Jin Su Jeong*

Departamento de Ingeniería Mecánica, Química y Diseño Industrial, Escuela Técnica Superior de Ingeniería y Diseño Industrial, Universidad Politécnica de Madrid, Ronda de Valencia 3, Madrid 28012, Spain

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ABSTRACT

Climate change is an obvious worldwide phenomenon closely related to human development, growth and consumption patterns, and it threatens land use, development, people and the environment. Due to its characteristics, Spain is among the most vulnerable countries to climate change in the European Union (EU). Thus, spatial planning is considered one of the main instruments available to manage sustainable adaptation to climate change. This article presents an assessment framework for exploring climate change impacts using participatory geographic information systems (PGISs)-multi-criteria decision analysis (MCDA) spatial planning with the preference ranking organization method for enrichment of evaluations (PROMETHEE) in sustainable land-use adaptation. Assessment planning applies to any agroforestry system at a regional level for a municipality with higher vulnerability. An indicator-based model with five categorical values was developed to assess twelve possible impacts from climate change and the main threats of climate change to water sources, agriculture, soil, and land management. This model is available to manage sustainable land-use adaptation priorities for climate change in a spatial context. The model discusses the likelihood of implementing and adopting strategies for climate change adaptation as assessed by a sensitivity analysis and a professional online survey. Among the five strategies, scenario A (suitability map) accounts for 8.84% of the priority areas (*v*) and 2.13% of the hot spots (*i*) and was the scenario most supported by professionals, while scenario D (priority to socioeconomic) accounts for 3.07% of the priority areas and 10.12% of the hotspots, and the lowest number of professionals supported this scenario. The results summarize foreseeable problems derived from climate change effects that require urgent adaptation activities through spatial land assessment planning. Thus, this study provides some recommendations and limitations from which decision-makers can select the most suitable arrangement for an agroforestry system to make it climate-resilient, and the study is applicable to similar geographical and spatial locations.

1. Introduction

There is a clear evidence that climate change is becoming global and caused by human influence (Adger et al., 2013; Brouziyne et al., 2018; Füssel, 2009; Smith et al., 2009). Climate change effects result in increasing temperatures and river run-off and higher precipitation levels and in global warming of the climatic system. These phenomena are expected to worsen and are a growing threat to quality of life quality over time (Bessembinder, 2008; Kleerekoper et al., 2012; Salcedo Rahola et al., 2009). Specifically, in the coming decades, climate change will be a significant driving force of landscape change, land-use change, building closely related to human growth, development, and consumption patterns (IPCC, 2007; Millennium Ecosystem Assessment, 2005; Mehdi et al., 2015). Although climate change is global problem, it has a great number of possible impacts that differ in intensity and degree, and most major local impacts are occurring in certain regions and sectors (European Environment Agency, 2008; Mehdi et al., 2015). Therefore, it is important to understand climate change impacts on land uses, buildings, landscapes and ecosystems to develop and apply adaptation strategies, to reduce the negative impacts and to increase the climate-resilience of physical and social structures within regions (Greiving and Schmidt-Thomé, 2008; Rannowa et al., 2010).

According to a report of European Environment Agency (2008), climate change impacts in Europe have demonstrated the high vulnerability of coastal and mountain areas as well as of the Arctic and the Mediterranean. Due to its socioeconomic and geographic characteristics, Spain is among the most vulnerable countries to climate change inside of the European Union (EU) (Estrela et al., 2012; Mehdi et al.,

* Corresponding author.
E-mail address: jinsu.jeong@upm.es.

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2015). It is predicted that a further increase in temperature and a further decrease in precipitation will occur according to forecasts obtained from models (Spanish Meteorological Agency, 2009). Since 1995, Spain has experienced significant economic development that is higher than the EU average, but the current economic recession is a critical threat (Pérez García et al., 2011; Extremadura Government, 2014). Thus, social growth in Spain indicates an important population increase that is translated into climate change consequences with growing greenhouse gas (GHG) emissions (Ministry of Agriculture, Food and Environment, 2013a). Specifically, in the Extremadura region, it an annual increase in GHG emissions has been observed according to the estimates by the Ministry of Agriculture, Food and Environment (Extremadura Government, 2014). However, territorial disconnection, systems vulnerability, various administrations and stakeholder involvement in decision-making processes make adaptation to address climate change effects difficult given their overarching and cross-sectoral characteristics (Greiving et al., 2006).

Since climate change threatens land use, development, and quality of life, spatial planning is reflected as one of key applications available to manage adaptation activities and their impacts in spatial contexts (Carter et al., 2015; Matthews et al., 2015; Millennium Ecosystem Assessment, 2005; Stern, 2007; Wilson, 2006). Additionally, the Food and Agriculture Organization (FAO) has delineated the significance of land-use planning, which involves the systematic evaluation of the potential and alternative land uses and the socioeconomic situations to adopt the best options (FAQ, 1996; Hou et al., 2017; NIAPP, 2000). Planning highlights environmental, ecological, and socioeconomic features, which need to be taken into account in the process. To satisfy this challenge, spatial planning decision-makers in the public sector require information on climate change impacts at a regional and/or local scale (Armatas et al., 2016; Biesbroek et al., 2009; Rannowa et al., 2010). In the context of participatory spatial planning (PSP), collaborative approaches are gaining support among authorities, and participatory approaches are being used for various reasons in operational terms (Cooke and Kothari, 2001; McCall and Dunn, 2012; Ribot and Larson, 2005). Thus, the multi-criteria decision analysis (MCDA) technique supports decision-makers, so they can explore and solve multiple and complicated problems in terms of PSP (Malczewski, 1999; Tassinari et al., 2013). Specifically, the preference ranking organization method for enrichment of evaluations (PROMETHEE) like as the MCDA technique is for assisting decision-makers. To put these concerns and inputs into maps, special capabilities are integrated in a geographical information system (GIS) (Saaty, 1977). The purpose of PSP is the spatial distribution of optimized land uses and decision-making about future lands uses (Ferraz et al., 2016; McCall and Dunn, 2012; Stumpf et al., 2018). Hence, PSP helps regional and local decision-makers implement climate change adaptation with coordination on measuring impacts and various interests and responsibilities (Ribot and Larson, 2005; Scott, 2014).

Spatial planning structures demonstrate the way that space is managed in place with different size and spatial distributions due to climate change impacts (Burger and Meijers, 2012; Carter et al., 2015; Millennium Ecosystem Assessment, 2005). Spatial planning also refers the land-use changes in urban/rural spaces and the influence of these changes on vulnerability and the spatial planning strategies that describe frameworks for actions for which climate change adaptation plays a significant role in terms of forming resilience and sustainability (Albrechts, 2004; de Vries, 2006). To understand the spatial structure forms, public space arrangement is crucial in developing spatial planning strategies for the benefit of people's socioeconomic quality and require climate change impact information at various regional scales (Matthews et al., 2015; Rannowa et al., 2010). Strategic spatial planning can be a public sector-led and social process based on a long-term goal that is combined with short-term activities and means for implementing the forms that a place may become (Kaufmann and Jacobs, 1987). Strategic spatial planning is about institutional design that is closely connected with the sustainable planning concepts, such as a positive-sum strategy merging environmental, social, and economic, that are implemented strategically at a spatial scale (Albrechts, 2004; Nguyen et al., 2015).

Combining certain instruments to identify proper strategies can enhance the use of climate change adaptation activities. There is no single, perfect strategy that can solve all problems immediately as mentioned by some researchers (CEC, 2009; Murphy et al., 2012). This paper evaluates twelve possible impacts grouped as three major criteria for climate change adaptation measures in sustainable land use to determine five categorical values (priority areas to hot spots, (*v*) to (*i*)). The assessment framework of an indicator-based model explores climate change impacts in the context of spatial PGIS-MCDA with PROMETHEE-based land assessment planning. The framework is applied to an agroforestry system at a regional level for a municipality in Spain with high vulnerability. The application of the framework using five implementation strategies allows a comprehensive evaluation of the impact addressed and an identification of the major impacts relevant for spatial planning in sustainable land use. Then, this paper discusses the likelihood of the adoption of the proposed implementation activities for climate change adaptation measures as assessed by an ArcGIS sensitivity analysis and decision-makers in an online survey. Thus, the mechanism behind the assessment framework can be identified through the cumulative results overlaid on the spatial patterns and the best and worst suitable strategy combinations, and this mechanism is instructive for enhancing adaptation activities and climate-resiliency concurrently.

2. Materials and methods

2.1. Case study description

The General Preliminary Assessment of the Impacts by Climate Change Effects in Spain (Ministry of Environment, 2005) presented reviewed and gathered information on climate change impacts that could have particularly serious consequences and on possible initiatives for adaptation in sustainable land use. In the Extremadura region, the current challenge that has arisen in developing active policies of regional government is related to the phenomenon of climate change (Extremadura Government, 2014). In this study, a case study area applied the assessment framework proposed at a regional level for a

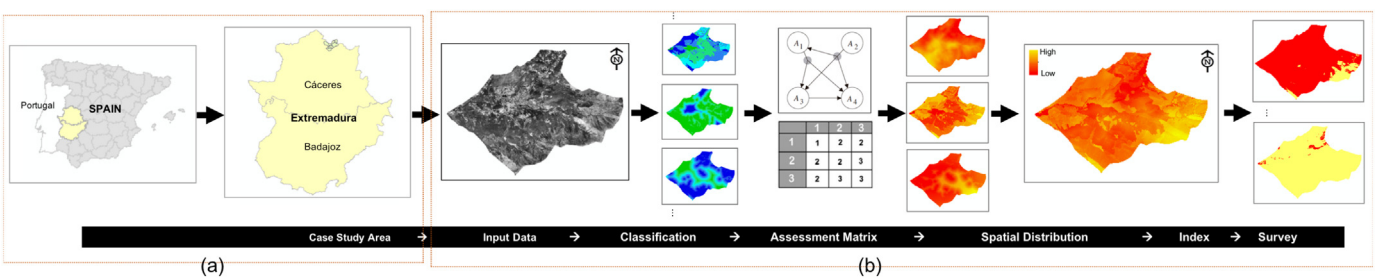

Fig. 1. (a) Pilot area for the Spanish case study; (b) Flowchart framework of the spatial PGIS-MCDA planning assessment.

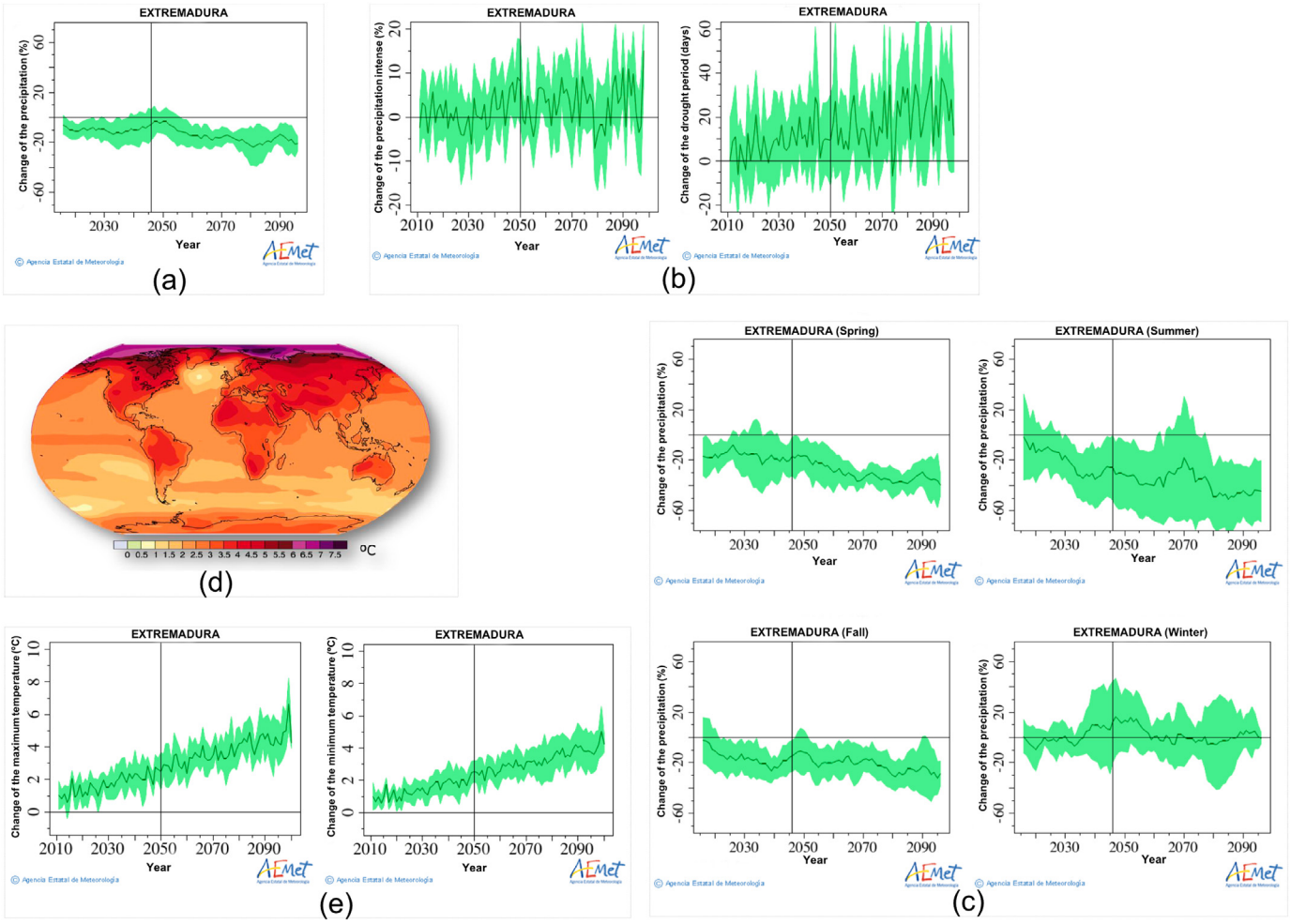

Fig. 2. (a) Change model of maximum and minimum average temperatures in Extremadura; (b) Change model of intense rainfall and drought period in Extremadura; (c) Change model of different precipitation based on four seasons in Extremadura; (d) Temperature increase model according to the multi-MCGAO method for 2090–2099; (e) Change model of precipitation in Extremadura.

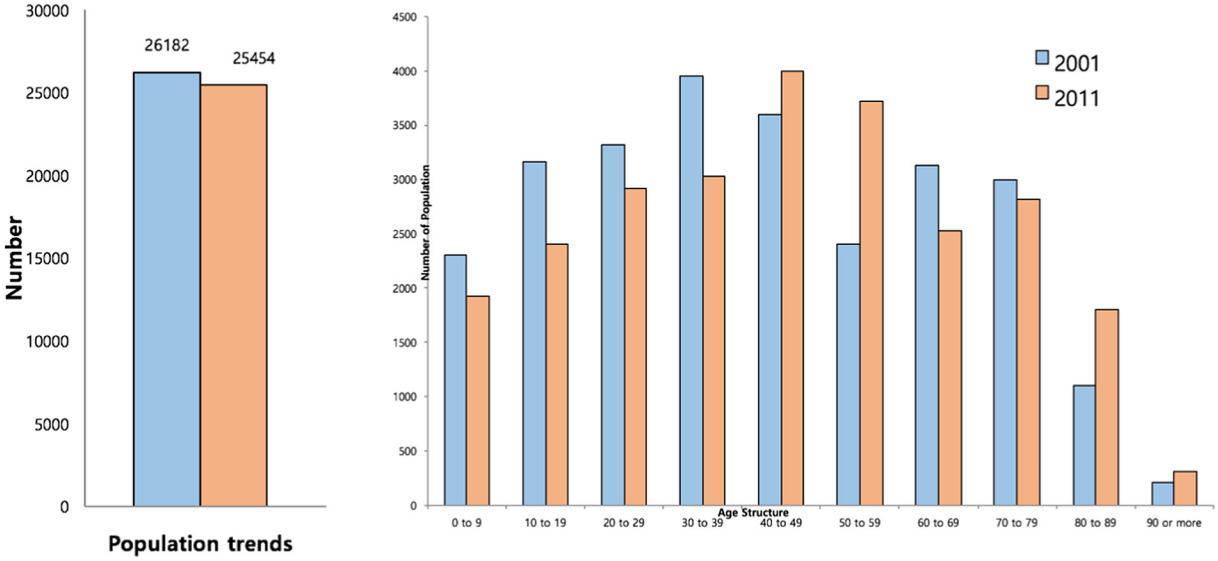

Fig. 3. Population trends and age structure in the case study area.

municipality with high vulnerability, Hervas, situated in the Ambroz Valley of the northern Caceres, Extremadura in Spain that is between 40°51′26″N and 5°16′57″W (its area is 60 km^2) as shown in Fig. 1a. Specifically, the climate of the case study area is distinguished by high spatial and temporal variability base on the aforementioned reports. In terms of precipitation, the average precipitation prediction of the area from the information collected from 1940 to 2010 shows a decrease in precipitation over a long period, which indicates that climate change impacts could worsen (Spanish Meteorological Agency, 2009). In Fig. 2a, for the period of 2010 to 2100, the annual precipitation decreases and can be expected to be 20% less in the final period (State Agency of Meteorology, 2013; Extremadura Government, 2014). Similarly, climatic behavior related to extreme weather events, such as intense rainfall and drought, has been studied, with the following data obtained as shown in Fig. 2b. A relative increase has been determined in terms of both days of intense rainfall and the duration of continuous dry periods, which indicate an increase in extreme weather events. Another climate variable model is the expected change in precipitation in each season of the year as shown in Fig. 2c. It has been concluded that throughout the 21st century, there will be a decrease in rainfall relative to the spring, summer, and autumn seasons. On the other hand, there will be a slight percentage increase in rainfall in the winter. In the case of temperature, the average temperature prediction for the area from the information collected from 1940 to 2010 demonstrates temperature will increase over a long period, which indicates that climate change impacts could worsen (see Fig. 2d) (IPCC, 2007; Spanish Meteorological Agency, 2009). In Fig. 2e, it can be seen that both the average maximum and minimum temperatures have increased by approximately 4 degrees (State Agency of Meteorology, 2013). Additionally, according to the Ministry of Agriculture, Food and Environment (2013b), there will likely be a further increase in temperature during the same period by the end of 21st century. In terms of geographical features, land use has been dominated by a multifunctional agrosilvopastoral system. This system corresponds to a specific cultural landscape that has high biological and scenic value with abundant rivers and wetlands, and it has experienced the most changes due to the gradual increase in human development and influence. Finally, in terms of social and economic aspects, their transformations in Extremadura including the study area have affected the age structure and population trends, initiating increased agricultural incomes that are paired with migration and movement to the countryside as shown in Fig. 3 (INE, 2011).

2.2. Land-use adaptation activities

The framework of the study contains a series of steps representing a logical progression from an assessment of the main threats from climate change to water sources, agriculture, soil, and land management (opportunities and risks) to the identification of adaptation activities and measures that are the most adequate for implementation. To identify the priority areas and hot spots for climate change adaptation measures in terms of sustainable land use, we determined a substantial assessment process that includes twelve possible impacts grouped as three major criteria in the context of spatial PGIS-MCDA planning. The main tasks of the assessment process are as shown in Fig. 1b:

- ✓ Collection of data containing spatial information associated with the case study area and standardization as GIS data;
- ✓ Identification of twelve possible impacts based on a literature review and expert discussions;
- ✓ Scoring of these adaptation options through the authors' decisions with a help of expert consultation;
- ✓ Spatial PGIS-MCDA planning analysis and assessment of these climate change-induced impacts using a pair-wise comparison method (PCM) and an analytic hierarchy process (AHP);
- ✓ Assessment of five categorical values (priority areas to hot spots) by overlaying the spatial patterns of climate change-induced impacts using weighted linear combination (WLC) and exploring the cumulative effects;
- ✓ Validation of five implementation strategies likely to be effective through a sensitivity and survey analysis.

In this assessment process, these adaptation choices were selected and identified based on various literature reviews and consultation with an expert panel to obtain the best catalogue for the various segments (criteria selection). The various source data were compiled and defined as a map with the aid of ArcGIS 10.3.1 ESRI software tools (ESRI Inc., Redlands, CA) from different ranges or value scales. The case study area was fully examined initially without removing hot spot areas for sustainable land-use adaptation to climate change impacts. This application combined authentic information such as geospatial data with worth-based information such as criteria weightings (Geneletti et al., 2003; Malczewski, 1999). With the criteria weightings obtained, the assessment framework of an indicator-based model allowed a comprehensive evaluation and comparison of the obtained results, five assessment classes, using WLC and a sensitivity analysis (criteria assessment). The assessment specified the spatial distribution of different possible impacts addressed in the case study area. The implementation strategies for cumulative impacts were validated first by the sensitivity analysis and then through the survey of professionals to overcome the negative impacts and to express possible responses (criteria validation) (De Bruin et al., 2009; Leonelli et al., 2017).

2.2.1. Selection of possible impacts and criteria in adaptation activities

Opportunities and risks were distinguished in relation to the projected impacts on land use in connection to participatory spatial planning. The selected twelve impacts that need to be addressed most immediately were evaluated with the rationale of concentrating the adaptation assessment on major issues. As a standardization process, the case study area was rasterized into a grid cell (10 by 10 m). In this study, all possible impacts are presented in a common value, 0–255 bytes grading scale, with fuzzy membership functions. The sigmoidal fuzzy membership function (“S-Shaped”) is the most commonly used function that is monotonically increasing and decreasing in fuzzy set theory (Eastman, 2003). The grading value 0 byte is assigned to the least suitable areas, and the grading value 255 bytes are allocated to the most suitable ones. This style represents how to alter the different valuation units of the factor images to equivalent suitability indexes. Tables 1-3 outline each possible impact with detailed characteristics and the calculated weight for the adaptation measure evaluation.

As the first PGIS-MCDA step, twelve possible impacts are involved in the computation process (see Fig. 4), distinguished by three major criteria. The first group contains possible impacts relevant to climate change threats (precipitation, temperature, environmental and water source) (see Table 1). The second group includes interlinked parameters of geomorphology criteria (agriculture, soil and land management) (see Table 2). The third group relates to socioeconomic parameters interwoven with socioeconomic effects (see Table 3). Four criteria relevant to climate change threats are analyzed as described in Table 1 and Fig. 4C1: (1) precipitation (loss of soil by water erosion, ground water level fluctuations, and water use fluctuations for industrial use); (2) temperature (heat waves); (3) hydrology (heavy rains, flash floods, river floods, and mass movements); and (4) biodiversity (loss of species). Four criteria relevant to geomorphology parameters are assessed as depicted in Table 2 and Fig. 4C2: (1) morphology (slope, elevation and orientation); (2) land-use and land-cover types; (3) vegetation types (forest fires); and (4) surface runoff. Four criteria relevant to socioeconomic considerations are examined as explained in Table 3 and Fig. 4C3: (1) population; (2) site access; (3) agricultural areas; and (4) urban areas (industrial areas and infrastructure destruction). The hierarchical formation of adaptation options consists of four stages: the first stage shows the main purpose, climate change adaptation activities

Table 1
Characteristics of the climate change criteria in the case study area with the computed weights.

Climate change criteria (C1)		
Probable impacts	Context of probable impacts	Calculated weights
Precipitation (R1)	Areas identifying an uneven distribution of annual precipitation make up the priority area of rural buildings and land-use adaptation. These areas also involve the impacts of the geomorphology criteria, mainly slope pairing with the complexity and percentage distribution of the land. The spatial representation of precipitation is depicted as shown in Fig. 4C1.	0.39
Temperature (R2)	Areas including those that appeal to the selection of the priority area of rural buildings and land-use adaptation. They also relate to the average value that influences the consideration of annual temperature increases in selecting the highest priority area in the case study area. The spatial representation of temperature is described as shown in Fig. 4C1.	0.28
Hydrology (R3)	Areas including water bodies such as springs and/or wells and main and second stream of water surface based on the EU Water Framework Directive (WFD, Directive 2000/60/EC) legislation and obligations for the priority area of rural buildings and land-use adaptation. The spatial representation of hydrology in the case study area is identified as shown in Fig. 4C1.	0.20
Biodiversity (R4)	Areas ecologically protected by the European Commission regulation for biodiversity and nature policy by NATURA 2000 and the regional law by LESOTEX (Law 15/2001, that is, terrestrial and landscape planning in Extremadura) for the priority area of rural buildings and land-use adaptation. The spatial representation of biodiversity is explained as shown in Fig. 4C1.	0.13

λ_{max} = 4.123; CI = 0.041; RI_4 = 0.9; and CR = 0.045 < 0.1.

in terms of sustainable land use; the second stage represents criteria to be evaluated that can support the main objective; third stage includes the subcriteria of each previous criterion; and the fourth stage demonstrates the spatial attributes of each previous subcriterion.

2.2.2. Assessment of sustainable land-use adaptation for climate change

PCM and AHP were utilized to remove the comparative importance weights of the criteria and their final scores and were applied to develop the assessment system (Saaty, 1996; Zeleny, 1982). As the process of participatory multicriteria spatial analysis (as the second PGIS-MCDA step), the authors with external expert consultation weighted and validated the scores of the proposed criteria. The specified hierarchical structure was made according to the observed importance of each criterion based on certain predetermined points of a scale (see Table 4) (Balana et al., 2010). A nine-point scale used here to conform the next attributes such as $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. An index called a consistency ratio (CR) indicates the PCM overall consistency, and the CR must have a value under 10% (Golden et al., 1989; Saaty, 1996; Vargas and Zahedi, 1993). A consistency index (CI) measuring the inconsistency in pair-wise comparisons can be determined as shown in Eq. (1) (Saaty, 1996). However, if the participatory weight assigned by the authors with expert discussion were not satisfying CR, then we suggested the adjusted weights to meet the CR close to the original weights.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

where $\lambda_{max}$is the largest eigenvalue that is always greater than or equal to row and column number (n). Correspondingly, a PCM coherence measure can be considered in the form of CR (see Eq. (2)):

$$CR = \frac{CI}{RI} \tag{2}$$

where the average CI of a random consistency index (RI) randomly generates comparisons (Saaty, 1996). A CR value of 10% or less is considered as acceptable. Otherwise, the decision maker has to revise his/her judgments (Kablan, 2004).

Then, the PROMETHEE outranking method was applied. Brans et al. (1986) developed the PROMETHEE, which is one of the MCDA methods. This method compares each pair of alternatives for each criterion values that vary between 0 and 255 intervals. It can be attained based on one of six different types outlined by Behzadian et al. (2010) that are (1) usual, (2) U-shape, (3) level, (4) V-shape, (5) linear and (6) Gaussian as depicted in Fig. 5. In the PROMETHEE, a selected preference structure leads to preference pointers $P_h(a_i, a_j)$ for the hth criterion that depends on the difference in the calculation of alternative a_i and alternative a_j for the selected criterion.

$$p_h(a_i, a_j) = x_{ai} - x_{aj} \tag{3}$$

Then, preference indexes are combined by the relative criterion weights (w_h) to the global preference index of a_i over a_j.

$$\pi(a_i, a_j) = \sum_{h=1}^{s} w_h \bullet p_h(a_i, a_j) \tag{4}$$

For the standardization of above three criteria with subordinated layers based on the weighted factors from Tables, theirs maps are created as follows:

Table 2
Characteristics of the geomorphology criteria in the case study area with the computed weights.

Geomorphology criteria (C2)		
Probable impacts	Context of probable impacts	Calculated weights
Morphology (R5)	Areas demonstrating basic topographic characteristics of the earth surface such as elevation, slope and orientation for the priority area of rural buildings and land-use adaptation. They also relate to atmospheric processes for environmental attribute derivation. The spatial representation of morphology is depicted as shown in Fig. 4C2.	0.06
Land-use and cover-types (R6)	Areas specifying natural states and economic development covering different land use and cover for the priority area of rural buildings and land-use adaptation. This probable impact differs from the vegetation type in that it considers economic development. The spatial representation of land-use and cover-types in the case study area is described as shown in Fig. 4C2.	0.57
Vegetation types (R7)	Areas indicating a significant environmental potential in relation to vegetation percentage on the ecological uniqueness and spatial spread for the priority area of rural buildings and land-use adaptation. They also describe the ecological uniqueness of vegetation using the normalized difference vegetation index (NDVI). The spatial representation of the vegetation type is as shown in Fig. 4C2.	0.25
Surface runoff (R8)	Areas identifying the water flow occurs when excess stormwater, melt water, or other resources flows over the earth's surface for the priority area of rural buildings and land-use adaptation. They also involve the impacts of the climate change criteria, particularly hydrological impacts. The spatial representation of the surface runoff in the case study area is described as shown in Fig. 4C2.	0.12

λ_{max} = 4.225; CI = 0.075; RI_4 = 0.9; and CR = 0.083 < 0.1.

Table 3
Characteristics of the socioeconomic criteria in the case study area with the computed weights.

Socio-economic criteria (C3)		
Probable impacts	Context of probable impacts	Calculated weights
Population (R9)	Areas showing one of socioeconomic criteria implies an influence density established by the 2011 census data provided of Spanish INE (see Fig. 3) for the priority area of rural buildings and land-use adaptation. Dense population influence sectors in towns, cities, and human settlements with economic distances. The spatial representation of the population is as shown in Fig. 4C3.	0.13
Site access (R10)	Areas describing the accessibility from the networks of existing roads outlining the origins of access such as highways, local roads and train railways for the priority area of rural buildings and land-use adaptation. The spatial representation of site access in the case study area is depicted as shown in Fig. 4C3.	0.15
Agricultural areas (R11)	Areas around the current agricultural fields more likely to undergo land-use changes in the priority area of rural buildings and land-use adaptation. They relate to the land-use cover types of the geomorphology criteria from the Landsat bands of a digital elevation model (DEM). The spatial representation of the agriculture areas in the cases study area is shown in Fig. 4C3.	0.49
Urban areas (R12)	Areas showing urban land-use and land-cover types for the priority area of rural buildings and land-use adaptation. The land cover employs an unsupervised categorisation that combines an iterative process of a random selection from the pixel spectral reflectance from a DEM. The spatial representation of the urban areas in the case study area is described as shown in Fig. 4C3.	0.23

$\lambda_{max} = 4.244$; CI = 0.081; $RI_4 = 0.9$; and CR = 0.090 < 0.1.

$$C1{:}Map = (R_1xW_1) + (R_2xW_2) + (R_3xW_3) + (R_4xW_4)$$

$$C2{:}Map = (R_5xW_5) + (R_6xW_6) + (R_7xW_7) + (R_8xW_8)$$

$$C3{:}Map = (R_9xW_9) + (R_{10}xW_{10}) + (R_{11}xW_{11}) + (R_{12}xW_{12})$$

After the third PGIS-MCDA step, the WLC method is the next step to assess three intermediate frameworks of an indicator-based model in the case study area. The WLC method is a relatively easy analytical method that can be applied when dealing with MCDA and that can be used in various situations. In this study, we extracted the final grading values that were given by the authors after consultations with the experts, and then, the criteria aggregation was performed to get final suitability map by applying WLC. To check the stability of the results acquired against the subjectivity of decision-makers, a sensitivity analysis was used Meszaros and Rapcsak, 1996). In this study, a sensitivity analysis was conducted by entering different group weights as described in Table 4 to clarify the stability of the results and making five different implementation strategies. On the other hand, by suitably

Table 4
Combination of criteria weights for the sensitivity analysis.

Scenarios	Criteria weights		
	Climate change	Geomorphology	Scio-economic
A. Suitability Map (SM)	0.62	0.28	0.10
B. Priority to Climate change (PC)	0.50	0.25	0.25
C. Priority to Geomorphology (PG)	0.25	0.50	0.25
D. Priority to Socio-economic (PS)	0.25	0.25	0.50
E. Equal Weights to groups (EW)	0.33	0.33	0.33

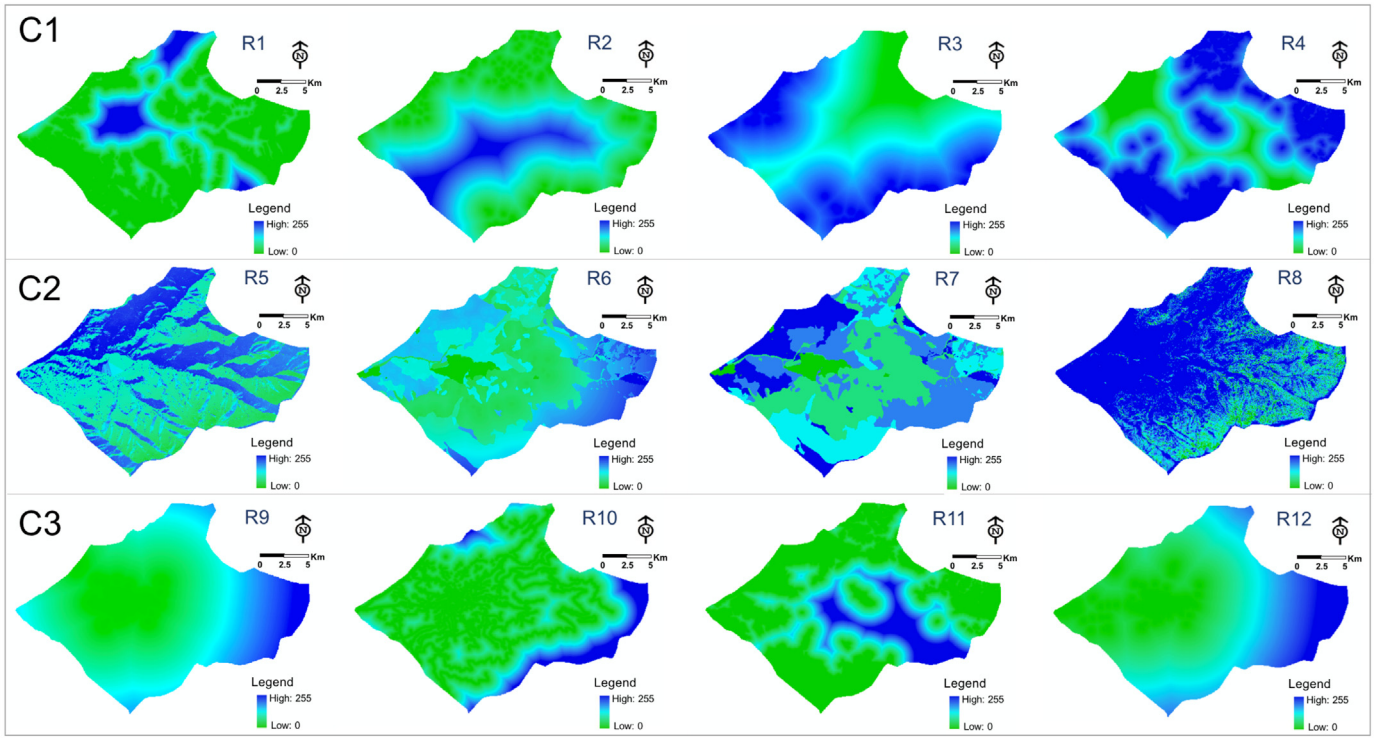

Fig. 4. Standardized twelve criteria maps; (C1) Climate change impacts; (C2) Geomorphology impacts; and (C3) Socioeconomic impacts.

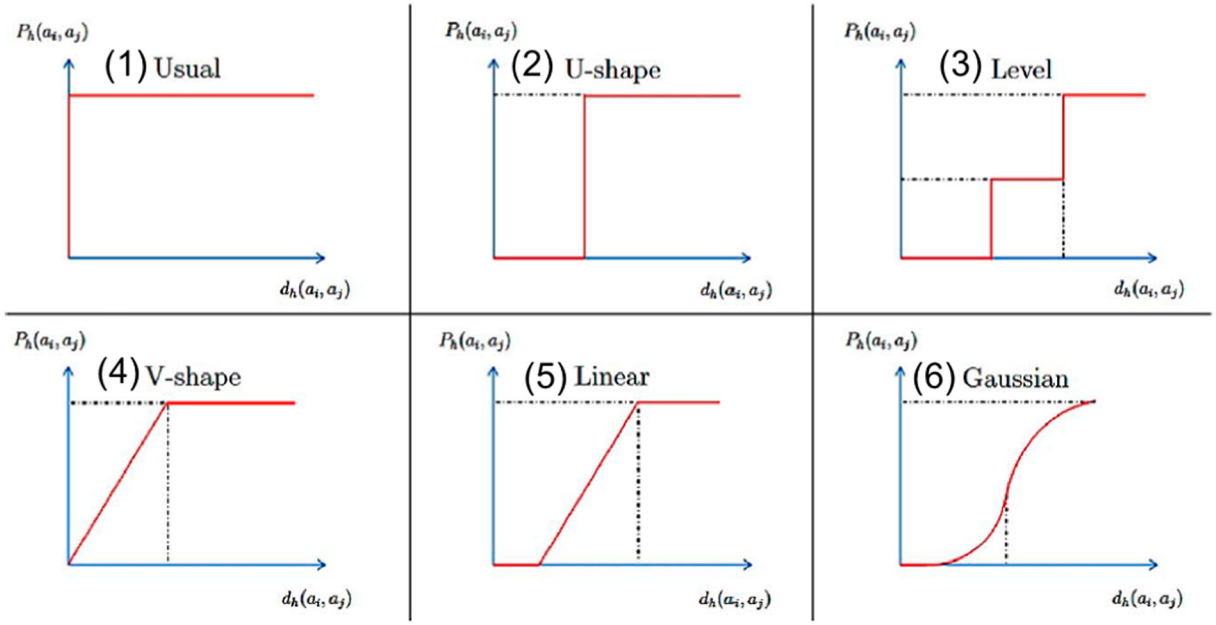

Fig. 5. PROMETHEE method functions for the criteria to be maximized Chou et al., 2007.

selecting the vector of weighting, it is likely to display different classes of correlations among the criteria combined. In the spatial implementation, WLC can be outlined with an *i*-th location such as a raster cell and an ordered weighted set, that is, $w = w_1, w_2, \ldots, w_n$:

$$w_j\,[0, 1] \text{ where } 1, 2, \ldots, \text{n and } \sum_{j=1}^{n} w_j = 1 \quad (5)$$

In this study, the suitability value of the multicriteria problem sets is computed on the basis of the grading scale used for the suitability index that is 0–255, and the higher score is, the more suitable area (Drobne and Lisec, 2009). This aggregation set technique multiplies factor weights by their factor score and subsequently sums the products to yield the suitability score as shown by Eq. (6).

$$V_i = \sum_{j=1}^{n} w_j v_{ij} \quad (6)$$

where V_i is calculated the sense of suitability index; w_j is weight of selected factor j; and v_{ij} is criterion score of factor j.

2.3. Survey modeling

As the fourth PGIS-MCDA step, the five proposed implementation strategies that were obtained from the previous sensitivity analysis are assessed in terms of those that could be likely to be effective and those that could be the highest priority and hot spots for sustainable land-use adaptation. As the broader objective is to generate strategies for decision-makers in Extremadura, it is essential to maximize the sample. Survey data were gathered with questionnaire-based emails with a web link. Specifically, the survey questionnaires avoided problems of motivating respondents and increased effectiveness by sending them only to people who were able to assess the implementation strategies (Gillham, 2000). The survey was designed with up-to-date standards that draw out individual inclinations from the large set of survey respondents (Kim et al., 2008; Reips, 2002).

A total of forty-two responses were collected through the online survey. The individuals contacted were involved in planning and policy-making on practical measures, and their scope of work encompassed land use, building and planning together with ecosystems and environmental issues. Most of the respondents held positions as professors, planners, architects, policy advisors, local authorities or managers. The vast majority of the respondents (over 80%) handle technical problems on a daily basis. The survey questionnaire consisted of three sections: the first section asks questions about the general background of the respondents such as their positions and fields of work; second, the respondents were asked to judge the likelihood of adaptation measures that would be executed if an assured strategy is applied; and third, the survey provides a section for commenting and a space for sending an email address if the respondent desires to be informed of the results at a later date. Specifically, in the second section, five implementation strategies, numbered A to E, are provided with a 5-point Likert scale, from 'very likely' to 'very unlikely'. Respondents could not continue to the next section until they had selected one of the answers. After measuring the likelihood of a strategy, respondents had the chance to explain their responses in an open text box. For this section, thirty-one respondents (74%) explained their answers for one or more implementation strategies. Their statements were post-coded to provide more generic descriptions for the assessments.

3. Results and discussion

In the present study, the final results obtained through the PGIS-MCDA spatial planning method was presented in terms of using the WLC and sensitivity test. The results of the indicator-based model were derived from the twelve possible impacts that were grouped into three criteria to demonstrate five categorical values (priority areas (*v*) to hot spots (*i*)) of sustainable land-use adaptation to climate change impacts. Then, these five different scenarios were evaluated by forty-two professionals through an online survey. Therefore, the results reflected the main patterns to address climate change vulnerabilities through a sustainable land assessment and planning.

Regarding the assessment framework for sustainable land-use adaptation to climate change, the maps presented in Fig. 4 include set elements that have discrete classifications in which the fuzzy set values are directly specified by the authors with expert consultation. Twelve possible impacts were analyzed by the computation process. As shown in Fig. 6, which was built based on the previous twelve possible impacts in Fig. 4, the WLC method is used first. Three intermediate maps were calculated and aggregated: climate change criteria is given a weight of 0.62; the geomorphology criteria is given a weight of 0.28; and the socioeconomic criteria is given a weigh of 0.10. Each weight of the criteria is assigned by the authors with expert consultation. Then, five different scenarios generated by the sensitivity analysis with different

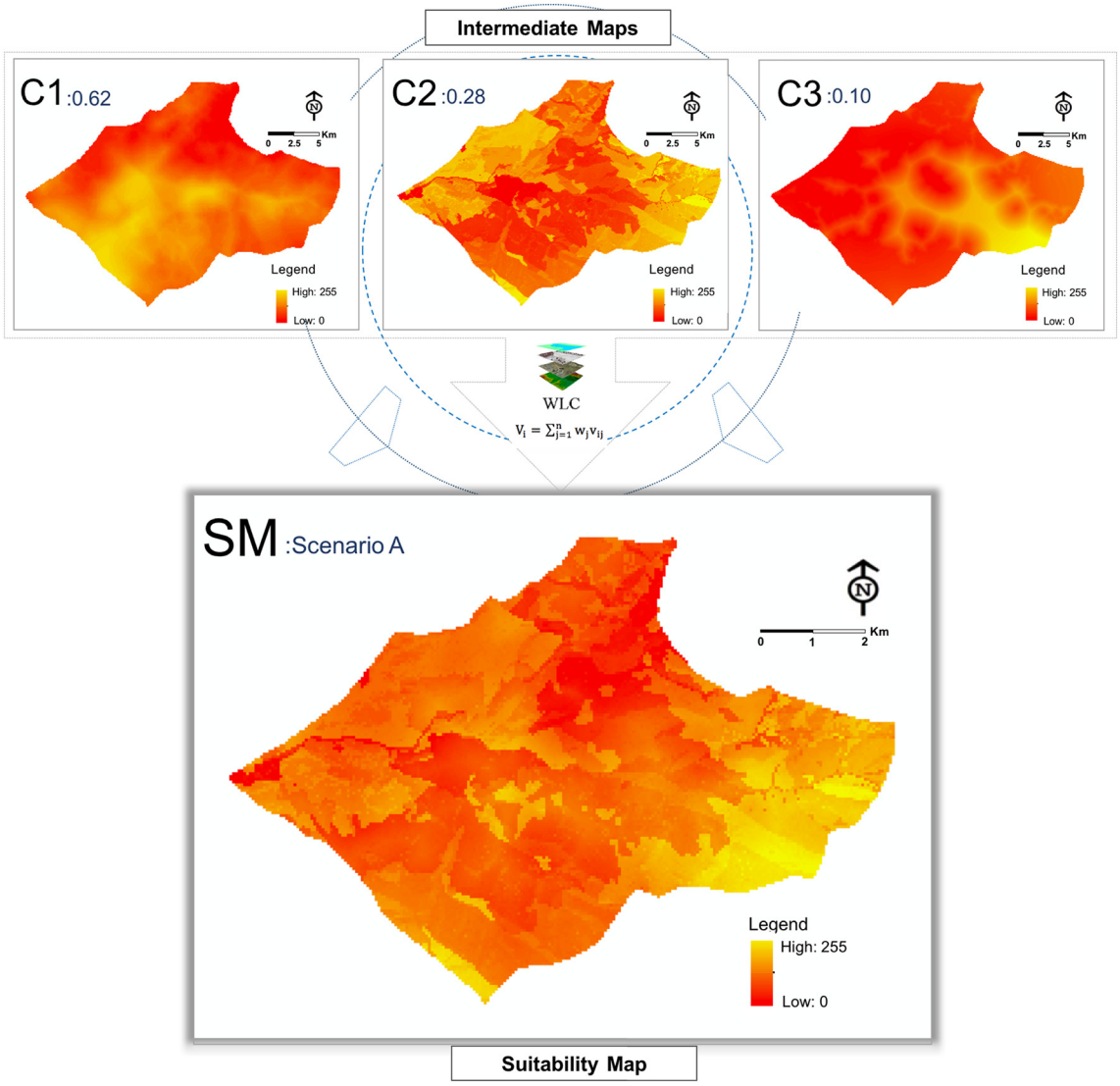

Fig. 6. Suitability map with the WLC extracted from three intermediate maps based on twelve probable impacts.

weights were applied to the three criteria. The maps of land-use adaptation to climate change are identified as the suitability index 0–255, that is, the higher the number is, the larger priority the area. Specifically, the five different scenarios A to E indicate the following: A is the suitability map based on the authors' weightings (0.62, 0.28 and 0.10 for three criteria climate change, geomorphology and socio-economic, respectively); B is priority to climate change criteria (0.50, 0.25 and 0.25 for three criteria climate change, geomorphology and socioeconomic, respectively); C is priority to geomorphology criteria (0.25, 0.50 and 0.25 for three criteria climate change, geomorphology and socioeconomic, respectively); D is priority to socioeconomic criteria (0.25, 0.25 and 0.50 for three criteria climate change, geomorphology and socioeconomic, respectively); and E is equal weights for all criteria (0.33 for all) based on Table 4.

As shown in Fig. 7, every indicator is classified to represent priority areas (*v*) and hot spots (*i*): every indicator is classified to represent a high (*v*), medium (*iii*) and low (*i*) status. Assessment matrices are used to unite and reclassify the indicators and specify a common index. This process provides comparable results for every impact notwithstanding the number of indicators used for the evaluation. For priority areas (*v*) for sustainable land-use adaptation to climate change, implementation strategy A was selected (8.84%), while hot spots (*i*) were related to scenario D (10.12%) where the socioeconomic criteria were favored. Scenario A had the least amount of hot spots (2.13%) compared with those in the other scenarios in this study. Among scenarios B to D, there was some difference, but it was not very obvious. Considering the area obtained, scenario A (suitability map) had the largest suitable area, 5.30 km^2. Additionally, in terms of scenario D (priority to socio-economic) that had the smallest suitable areas, 1.84 km^2, there was a 3.46 km^2 or 5.77% difference between it and scenario A. Specifically, in Fig. 8, the five different implementation strategies (see Fig. 7a) explained above were considered feasible for the effective implementation of sustainable land-use adaptation to climate change because they combined the theoretical approaches, reciprocally compensating for their weak points. Additionally, the results of the sensitivity analysis demonstrated that the paradigm created by the WLC had high reliability and suitability. The individual conceptual approaches were evaluated by the professionals; thus, this work sheds light on what a larger sample of professionals considers are the chances of implementation for the five implementation strategies shown in Table 5 and Fig. 7b. These results are also supported by the five-point Likert scale by the forty-two professionals. Scenario A obtained a score of 29% very likely, while scenario D obtained 7% very likely. Based on the map analysis and survey analysis, interestingly, we found that both analyses favored scenario A, and scenario D was the least favored. Additionally, there was a difference between scenarios C and E, but it was not a

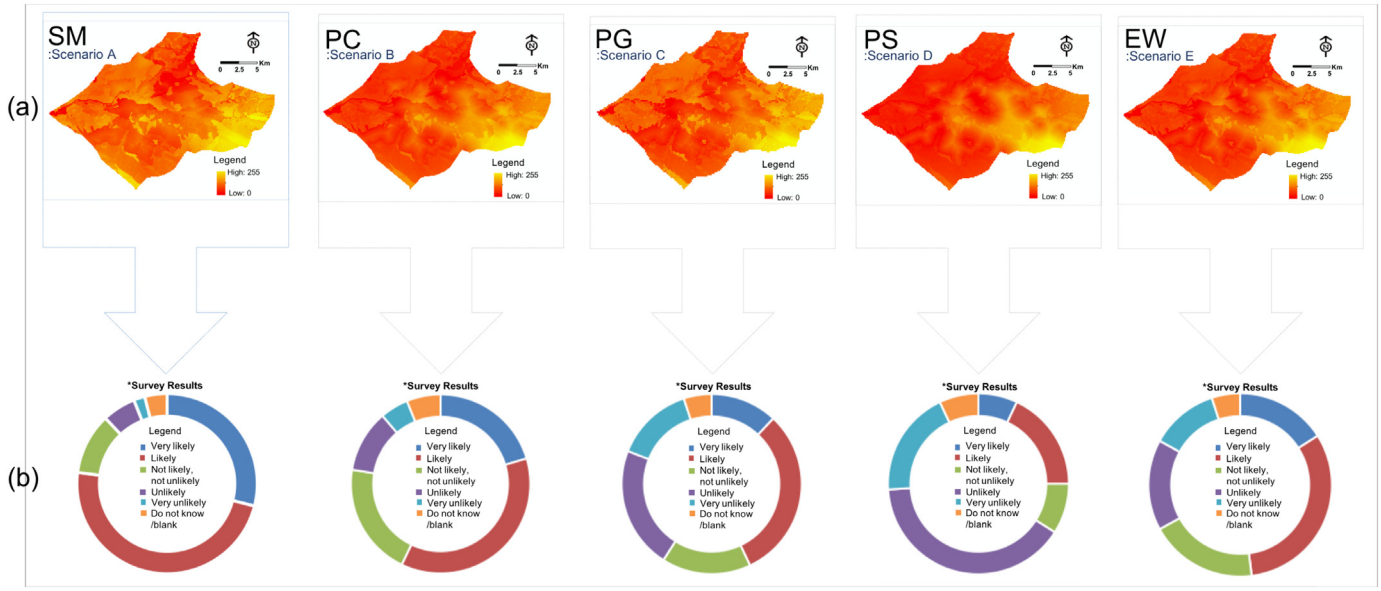

Fig. 7. (a) Five maps from the WLC and sensitivity analysis; (b) Likert scale survey analysis.

significant difference. Therefore, the implementation strategies are considered feasible for the effective implementation of sustainable land-use adaptation to climate change.

The results of the WLC, sensitivity analysis and survey analysis generated different spatial patterns and likelihoods of participants to support twelve possible impacts and three criteria. The results also show that this approach can reveal an indicator-based model (priority areas (*v*) and hot spots (*i*)) for the adaptation of sustainable land-use assessment planning to climate change and the possibility of the efficient implementation of five different implementation strategies compensating for their weak points. The methodology and the results proposed can be applied to sustainable and resilient planning policies at all levels of government and private sectors, including similar geographical locations, in terms of decision-making procedures due to the

Table 5
Likelihood of the implementation strategies by the professionals survey.

Answer category		Implementation strategy				
		A	B	C	D	E
5	Very likely	29%	20%	12%	7%	16%
4	Likely	48%	36%	31%	18%	32%
3	Not likely, not unlikely	11%	20%	16%	9%	19%
2	Unlikely	6%	11%	22%	40%	16%
1	Very unlikely	2%	5%	14%	19%	12%
0	Do not know/blank	4%	6%	5%	7%	5%
Overall assessment		3.84	3.31	2.90	2.33	3.09

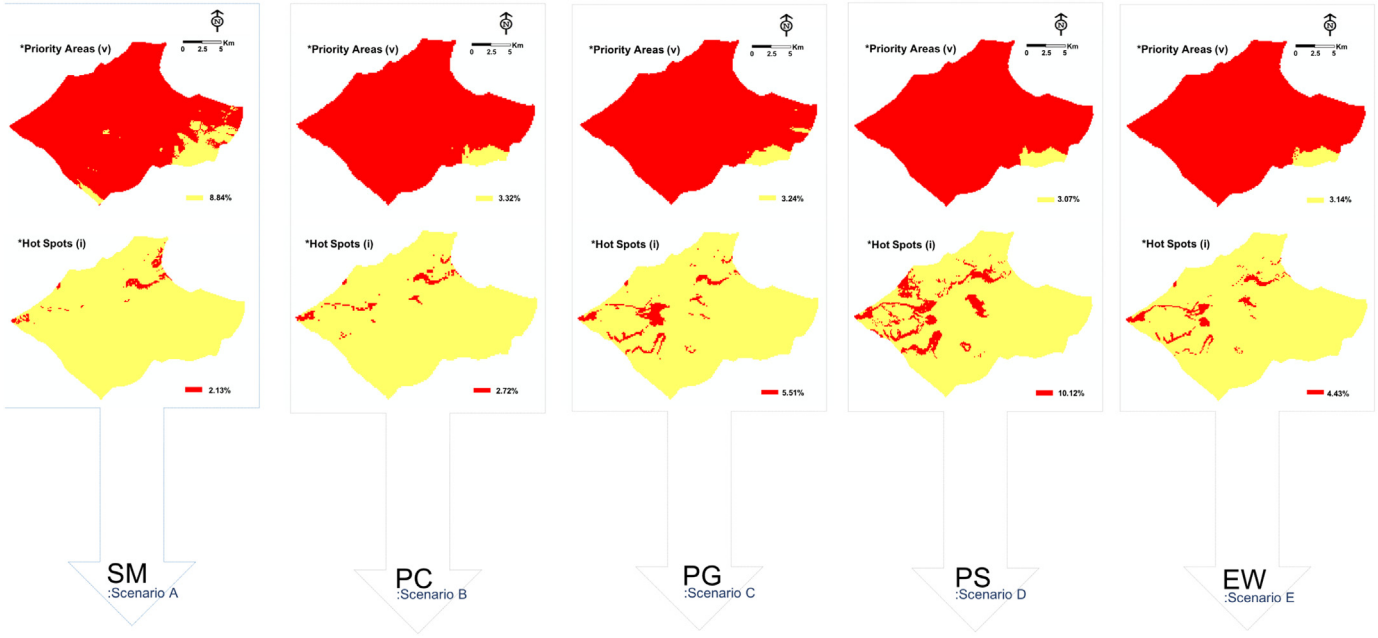

Fig. 8. Priority areas and hot spots of the five scenarios.

flexible nature of the methodology. The results summarize foreseeable problems derived from climate change effects, with options and activities for sustainable land-use adaptation priorities that have not yet been sufficiently utilized.

4. Conclusions

This paper presents an assessment framework for investigating climate change impacts in terms of the spatial PGIS-MCDA with PROMETHEE-based land assessment planning, particularly for sustainable land-use adaptation priorities, in Hervas (Extremadura region), Spain. An indicator-based model represents an important decision-making procedure for the adaptation of sustainable land-use planning to climate change and for the use of various resources that reflect the main threats from climate change to water sources, agriculture, soil, and land management. The principal benefits of this approach are criteria selection, weighting and analysis (WLC and sensitivity analysis) by decision-makers; validation by survey participants; the ability and flexibility to incorporate data in GIS; and the twelve criteria grouped into three criteria, namely, climate change, geomorphology and socioeconomic group.

The spatial PGIS-MCDA planning method based on a land assessment was used to determine the possible impacts and their importance, the WLC and the sensitivity analysis were used to summarize the criteria weights with priority areas and hot spots, and different implementation strategies were evaluated by forty-two professionals in terms of sustainable land-use planning for climate change adaptation in the agroforestry case study area. The professionals used a grading scale of 0 to 255, from the least appropriate areas to the most appropriate area. The results obtained of the indicator-based model for scenario A indicated that 8.84% of the case study area was a priority area (v) from a sustainable land-use adaptation view of climate change, while 2.13% of the region had no suitable value (hot spots (i)). Regarding the sensitivity analysis with the professionals survey, scenario A (suitability map) had the largest suitable area at 5.30 km^2. Additionally, scenario D (priority to socioeconomic) had the smallest suitable area at 1.84 km^2, and there was a 3.46 km^2 and 5.77% difference between these two scenarios. The results of sensitivity analysis demonstrated that the paradigm created by the WLC had high reliability and suitability. These results were also supported by the five-point Likert scale used by forty-two professionals. Scenario A received a score of 29% very likely, while scenario D received a score of 7% very likely. The described implementation strategies were judged in terms of their feasibility of being effective and their applicable implementation in terms of sustainable land-use adaptation priorities for climate change impacts.

The results present the new information on the spatial distribution of different possible impacts addressed in the case study area. This study provides a unique decision-support method for sustainable land-use planning and implementation strategies with input from professionals, and this study fills a niche of multicriteria techniques and spatial analyses on climate change. Areas with cumulative impacts from climate change are recognized as hot spots, and they require urgent adaptation activities through spatial planning. This study also summarizes foreseeable problems resulting from climate change effects and offers some suggestions that can be selected in the most suitable combination. The proposed methodology and the results can be used for sustainable planning policy at all government levels and in all private sectors because of its flexible characteristics, while also bearing in mind its limitations. Thus, this approach could support suitable sustainable land uses in agroforestry systems with similar geographies and conditions. As climate change impacts intensify in the coming decades, many adaptation measures and actions that have been adopted will need to be reinforced or expanded across wider areas.

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